CHAPTER 8

Pathogens in Soils and on Plants

INTRODUCTION

The early literature dealt with land application of sewage, effluent, or low-solids sewage sludge (Sepp, 1971). This literature raised concerns about the use of raw sewage, which could result in animal or human health infections (Bicknell, 1972; Dunlop et al., 1951; Dunlop and Wang, 1961). Currently, the practice of applying untreated sewage or sludge is prohibited. The USEPA 503 regulations allow land application of biosolids (treated sewage sludge) either as Class A or Class B material (see Chapter 11 on Regulations).

The existence of pathogens in soils and on plants depends on their survival of the wastewater treatment processes and biosolids treatment, method of land application, soil conditions, and environmental conditions. Although many of the biosolids' processes can result in very effective disinfection and the application of these biosolids does not represent a health hazard, public perception may be sufficiently significant so that applying biosolids to certain food chain crops must be avoided. Figure 8.1 shows the potential routes of pathogen transmission to humans and animals. Food chain crops that are cooked or processed would have no potential for infection. These would include crops for oil (soybeans, sunflower, and canola) or canned foods. Food crops that would not come in contact with biosolids, such as fruit trees (citrus, nut, pears, apples, etc.), would also not harbor pathogens and would not be a potential source of infection. Nonfood chain crops such as fiber (cotton) or forest would also not present a hazard to humans or animals.

Although Class B biosolids can contain pathogens, USEPA provided site restrictions to preclude potential impact to human and animal health and environmental consequences. These site restrictions were based on the potential survival of pathogens in the environment.

When low-solid biosolids are applied by spraying on land, the potential exists for pathogens to be aerosolized. Workers, in particular, may be subjected to these pathogens and become infected. Contamination of water resources, especially drinking water, can result from the movement of pathogens through the soil or in runoff into surface waters.

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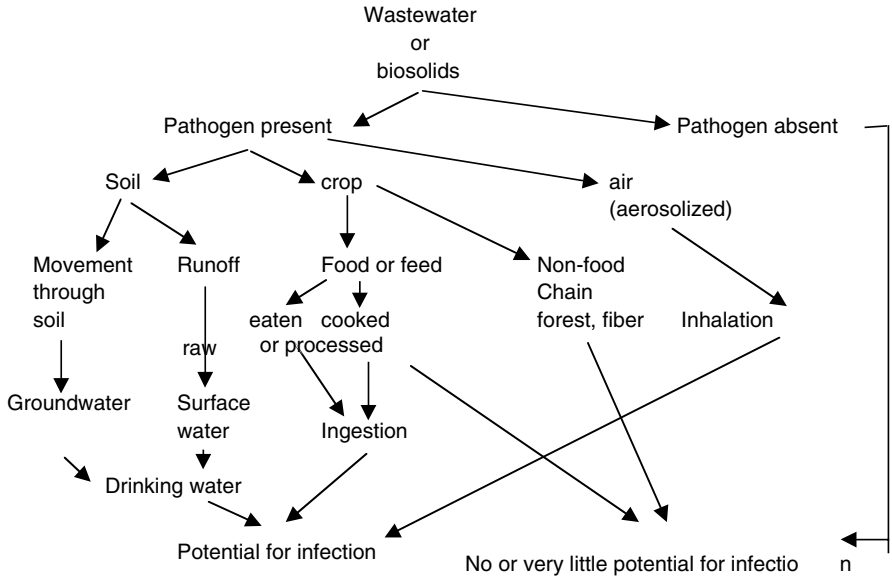

Figure 8.1 Potential routes of pathogen transmission to humans and animals

Since pathogens survive the wastewater treatment processes (primary and secondary treatment), land application of sewage sludge directly from these processes needs to be avoided or restricted to land management systems. This would ensure minimal potential for environmental contamination or health hazards to humans and animals.

Further treatment, such as digestion, composting, alkaline stabilization, or heat drying, increases the opportunities for land application. Composted products can be used as soil conditioning materials for agricultural and horticultural applications such as landscaping, nurseries, parks, public work projects, and home gardens. Alkaline stabilized biosolids can be used as lime products and soil amendments for agriculture and horticultural practices, such as turf production and certain public works projects. Heat-dried materials are often used as substitutes for chemical fertilizers.

Pathogen survival in soils or plants depends on several factors:

- Climatic and microclimate effects
- Soil physical properties
- Soil chemical properties
- Soil microbial populations
- Plants' exposure to weather

PATHOGENS IN SOILS

The survival and potential movement of pathogens through soils to groundwater depend on several edaphic and climatic factors. The most important are soil moisture,

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pH, temperature, organic matter, soil texture, soil permeability, sunlight, and antagonistic microflora.

Exposure to sunlight and ultraviolet light will destroy pathogens on the soil surface and on plants. Desiccation and temperature will destroy organisms on the soil surface. Soil physical properties such as soil moisture, soil temperature, organic matter, and ionic strength can affect pathogen survival and movement through soils.

Rudolfs et al. (1950) summarized the literature prior to 1950 on the occurrence and survival of enteric, pathogenic, and relative organisms in soil, water, sewage, sludges, and vegetation. They concluded from the early literature survey that the following soil factors affect the survival of pathogenic microorganisms:

- Type of organism — *E. coli*, *E. typhosa*, and *M. tuberculosis* appear to be most resistant.
- Soil moisture content — longevity is greater in moist soils.
- High soil moisture holding capacity increases longevity.
- Soil pH — neutral soils favor longevity.
- Organic matter — the type and amount of organic matter may serve as a food and energy source to sustain or allow bacteria to increase.
- The presence of other microorganisms reduces the presence or concentration of pathogenic organisms.
- Temperature — pathogenic organisms survive longer at low temperatures.

Other literature reviews were provided by Dunlop (1968) and Sepp (1971). Gerba et al. (1975) reviewed the literature prior to 1975 and substantiated some findings by Rudolfs et al. (1950) on soil factors. They indicated that sunlight also reduced the survival time on soil surfaces. Reddy et al. (1981) provided a comprehensive review of the behavior and transport of microbial pathogens and indicator organisms in soils treated with organic wastes. They also concluded that the most important factors affecting the die-off rate were temperature, moisture, pH, and method of waste application. Die-off doubled for temperature increases of 10°C, and also rose when soil moisture was reduced. Retention of microorganisms increased with an increase in clay content of the soil. Table 8.1 shows the average die-off rates for selected indicator organisms and pathogens.

The decay die-off rates for *Salmonella typhimurium* and fecal coliform were in the range that Reddy et al. (1981) had shown. The *Shigella sonni* decay coefficient rate was lower. Evens et al. (1995) conducted studies and concluded that *S. sonni* and fecal coliforms were found to survive longer on average than *Salmonella typhimurium*. Casson (1996) also conducted a laboratory study and showed that 2 log reductions were found after 10 to 20 days. Decay rates ranged between 0.08 log per day to 0.4 log per day.

Bacteria

Shortly after the discovery of *Eberthella typhosa* as the causative organism for typhoid, attempts were made to determine its survival in soils. According to Rudolfs et al. (1950), Granger and Deschamps in 1889 claimed to recover the organism from soil after 5.5 years. Also, Karlinski in 1891 reported that *E. typhosa* survived in soil

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Table 8.1 Die-off Rate Constants (Day^{-1}) for Selected Indicator Organisms and Pathogens in a Soil-Water-Plant System

Organism	Average	Maximum	Minimum	SD ±	C.V. %	No. of Observations
Escherichia coli	0.92	6.39	0.15	0.64	179	26
Fecal coliforms	1.53	9.10	0.07	4.35	283	46
Fecal streptococci	0.37	3.87	0.05	0.69	188	34
Salmonella sp.	1.33	6.93	0.21	1.70	128	16
Shigella sp.	0.68	0.62	0.74	0.06	9	3
Staphylococcus sp.	0.16	0.17	0.14	0.02	14	2
Viruses	1.45	3.69	0.04	1.44	99	11

Source: Reddy et al., 1981, *J. Environ. Qual*. 10(3): 255–266. With permission.

for 3 months. Melick (1917) reported that *E. typhosa* survived from 29 to 58 days, depending on the soil type. In a sandy soil, survival lasted for 74 days. Kliger (1921) indicated that moist, alkaline conditions in soils were most favorable for the survival of pathogens. Beard et al. (1937) and later Beard himself (1938, 1940) reported that soil water holding capacity, temperature, precipitation, sunlight, soil pH, and soil organic matter all affected the survival of typhoid bacillus. The data showed that the survival of *E. typhosa* was greatest in soils during the rainy season. In sand, where drying is more rapid, the organism survived for a short time — between 4 and 7 days. However, in soils that retained moisture, the organism persisted for longer than 42 days.

Van Dorsal et al. (1967) found a greater die-off rate for *Escherichia coli* and *Streptococcus faecalis* in soil plots exposed to the sun, than those in the shade. The authors also reported that 90% of fecal coliform in the soil were reduced in 3.3 days in the summer and 13.4 days in the winter.

Bacteria can move through soils to great depths. Romero (1970) reported that after 2 days, fecal coliforms and fecal streptococcus organisms were observed to travel over 500 m (1500 ft) after the application of tertiary treated wastewater. This movement occurred in coarse gravel. Several other early authors reported that bacteria could move through soils to depths ranging from <1 m to 830 m. The soils facilitating deep penetration were sand, sandy gravel, and gravel.

The majority of the studies have shown that the movement of bacteria in soils is restricted to less than 30 ft and should not percolate into groundwater (Butler et al., 1954; McGauhey and Krone, 1967). These studies focused primarily on the use of wastewater or very low biosolids concentrations.

Pathogens in dewatered or high-biosolid material applied to land will not likely leach out and move through the surface soil to groundwater. The movement of bacteria where dewatered biosolids are applied is markedly different from with wastewater. Surface application, including tilling or incorporating biosolids into the upper 15 cm (6 in.), greatly reduces the survival and movement of bacteria. Andrews et al. (1983) found that when biosolids were injected into the soil, 90% were inactivated after 17 days in the winter and 3.7 days in the summer.

Sorber and Moore (1986) reviewed the literature prior to 1986 and concluded that quantitative data describing pathogen survival or transport in biosolids-amended

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soil were extremely limited. Their data are shown in Table 8.2. Generally, some salmonellae bacteria and indicator organisms survived for several weeks. Median die-off rates for indicator bacteria, fecal coliform, fecal streptococci, and total coliform were lower than those observed for *Salmonella*.

The literature review presented by Sorber and Moore (1986) revealed that with one exception, a 90% reduction in *Salmonella* was observed within 3 weeks of biosolids application. These studies were conducted with both indigenous and seeded organisms (Andrews et al., 1983; Jones et al., 1983; Kenner et al., 1971; Larkin et al., 1978). These authors indicate that seeded *Salmonella* organisms often showed higher persistence. They suggested that could be as a result of the very high concentrations, 10^6 to 10^9 per liter, that were land applied. In field studies, indigenous *Salmonella* generally persisted for less than 2 months, with few positive recoveries reported for as long as 3 to 5 months.

Strauch et al. (1981) evaluated the survival of seeded salmonellae in biosolids applied to forest land. The soils were sand and marl. The average temperature was 8.3ºC and average precipitation was 739 mm. *Salmonella* survived from 270 to 640 days. Watson (1980), in a study in England, found that organic matter, pH, temperature, and the physical state of the organism affected *Salmonella* survival when digested biosolids was applied to land. *Salmonella* concentrations dropped from 100,000,000 to zero in 42 to 49 days.

The sieving effect of soil, which is influenced by particle size, texture (i.e., clay vs. sand), and adsorption, can greatly reduce bacterial movement. Alexander et al. (1991) studied the factors affecting the movement of bacteria through soil. They measured sorption partition coefficient, hydrophobicity, net surface electrostatic charge, zeta potential, cell size, encapsulation, and flagellation of the cells using 19 different bacterial strains. The results indicated that adsorption greatly contributed to the retention of bacteria, and that bacterial movement through aquifer sand was enhanced by reducing the ionic strength of the in-flowing solution. Cell density and flow velocity also affected bacterial movement. The data revealed that the potential for bacterial contamination of groundwater from the application of biosolids is very minimal. Studies in which bacteria were inoculated in sterile and nonsterile soil showed that pathogens were suppressed by the presence of other soil organisms. Bryanskaya (1964) showed that actinomycetes suppressed the growth of salmonellae and dysentery bacilli.

Pepper et al. (1993) conducted both laboratory and field studies using total coliforms, fecal coliforms, and fecal streptococci organisms. They found that moisture, temperature, and texture of soil affected the survival of these indicator organisms. Survival of organisms was enhanced by increasing soil moisture and clay content and diminished by higher soil temperature. Under field conditions, when rainfall increased soil moisture, regrowth of indicator organisms occurred.

Although concentrations of fecal coliform, fecal streptococci, and *Salmonella* concentrations decreased through an extended hot, dry summer and were not detected, repopulation occurred after precipitation (Gibbs et al., 1997). The authors indicate that despite apparent die-off of salmonellae, land to which biosolids have been applied may be subject to *Salmonella* repopulation. Management needs to take this into account to protect public health.

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Table 8.2 Survival of Several Microorganisms in Soil

Organism	Depth (cm)	Die-off Rate - T_{90} Days[1]				Die-off rate T_{99} Days[2]			
		Min.	Max.	Median	Obs.[3]	Min.	Max.	Median	Obs.
Salmonella	0–5	6	61	12	11	11	45	22	8
	5–15	4	22	15	8	7	45	30	6
Fecal streptococci	0–5	7	28	17	10	14	63	24	8
	5–15	NA	NA	NA	NA	NA	NA	NA	NA
Fecal coliform	0–5	7	84	25	19	12	165	60	16
	5–15	4	49	16	10	9	56	32	9
Total coliform	0–5	16	170	40	7	28	350	155	4
	5–15	35	70	42	3	NA	NA	NA	NA
Viruses	0–5	<1	30	3	9	2	52	6	6
	5–15	30	56	30	3	60	100	60	3
Parasites	0–5	17	270	77	11	68	500	81	5
	5–15	NA	NA	NA	NA	NA	NA	NA	NA

[1] T_{90} = 90% reduction within the days indicated.
[2] T_{99} = 99% reduction within the days indicated.
[3] Obs. = Number of observations.

NA = Data not available.

Source: Adapted from Sorber and Moore, 1986.

Land application of biosolids can result in runoff and potential contamination of surface waters. This would be especially true if the biosolids were not incorporated into the soil prior to rainfall (Evens et al., 1995). Land application of biosolids to highly porous soils, following significant amounts of precipitation, could result in some movement of pathogenic organisms for several meters. However, unless the groundwater levels are very shallow, there is little potential for contamination of groundwater. Biosolids application modifies soil properties, which increases the retention and removal of pathogens. Increased organic matter will lower water percolation and enhance water retention in sandy or gravelly soils. Biosolids application modifies pH, which could affect bacterial survival. This is especially true if the pH is increased through liming. The increased organic matter from biosolids' application enhances the indigenous microbial population that could result in pathogen inactivation.

Viruses

Data on viruses in soil from the application of biosolids are meager. However, considerable information is available on viruses from effluent application to land. Viruses in effluents have much greater potential to move through soils and therefore represent much worse scenarios. Movement with liquid media is more rapid than

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by leaching from a solid matrix. Furthermore, viruses are adsorbed on the solid surfaces and less apt to leach. The organic matter in biosolids would also affect the adsorption of viruses.

The survival of viruses and their movement through soil are greatly affected by soil properties. They generally do not survive very long outside their hosts. They contain a nucleic acid core surrounded by proteins. Viruses are electrically charged colloidal particles and thus capable of adsorbing onto soil surfaces. Many of the studies utilized bacteriophages as models. A bacteriophage is a virus with specific affinity for bacteria (*Stedman's Medical Dictionary*, 1977).

The early studies on the adsorption of viruses onto soil surfaces were reviewed by Bitton (1975). Drewry and Eliassen (1968) studied virus retention in soils and concluded that virus adsorption was affected by the soil-water system pH. Carlson et al. (1968) studied the adsorption of bacteriophage T_2 and type 1 poliovirus to kaolinite, montmorillonite, and illite clays. The type and concentration of cations present in soil water affected sorption of viruses under similar ionic conditions. Kaolinite and montmorillonite adsorbed the same amount of viruses. Illite required twice as much salt to attain the same binding capacity. The authors concluded that the surface exchange capacity, determined by the surface density and clay particle geometry, was important in the adsorption process.

Adsorption is more rapid at a lower pH. Bagdasaryan (1964) reported that enteroviruses survived in loamy and sandy loam soils for prolonged times. The adsorption of viruses to soil may prolong their survival (Gerba et al., 1975). Wellings et al. (1975) indicated that viruses survived in soil for 28 days and were capable of moving through the soil. Tierney et al. (1977) also found that poliovirus type 1 inoculated in raw and activated sludge survived in soils for up to 96 days in the winter. Damgaard-Larsen et al. (1977) discovered that it took 23 weeks during a normal Danish winter to inactivate 10^6 $TCID_{50}$/g of Coxsackievirus B3. Under warm, humid conditions in Florida, Farrah et al. (1981) reported a two $\log_{10}$ drop in titer of indigenous viruses in biosolids-amended soil. Gerba (1983) indicated that virus inactivation occurs in the top few centimeters of soil where drying and radiation forces are greatest.

Bitton et al. (1984) evaluated virus transport and survival after land application of biosolids. Strains of poliovirus type 1 and echovirus type 1 were mixed with anaerobically and aerobically digested biosolids and applied to the soil and mixed with the top 2.5 cm of soil. Neither the poliovirus nor echovirus was detectable in soil after being exposed for 8 days to dry fall weather conditions. Under summer weather conditions in Florida, poliovirus was detectable in the soil for 35 days.

Generally, viruses are adsorbed on clays and the adsorption capacity increased with clay content, cation exchange capacity, specific surface, and organic matter. It has been shown that virus adsorption in natural soils follows the Freundlich isotherm:

$q = K_F C^{1/n}$

q = the amount of virus in PFU/g of soil

C = concentration of the virus at equilibrium in PFU/ml solution

K_F = the Freundlich constant determined by the y axis intercept from a plot of q vs. log C

$1/n$ = the slope of the line as determined by the above plot

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Burge and Enkiri (1978) showed that the amount of virus adsorbed by five soils was linearly related to the square root of time. There was a high negative correlation with pH, as would be expected, due to their amphoteric nature. The lower the soil pH, the more positively charged the virus particles.

Viruses are removed from percolating water by adsorption on soil particles. Lance et al. (1980) found that poliovirus type 1 essentially remained in the top 5 cm. Other factors are soil type, iron oxides, pH, cations, and virus type. Gilbert et al. (1976) reported that human bacterial and viral pathogens are largely removed as sewage effluent percolates through the soil, and do not move through soil into groundwater. The viruses measured included polio, echo 15, Coxsackie B4, reovirus 1 and 2 and undetermined types. The bacterial indicators and pathogens were: fecal coliforms, fecal streptococci, and *Salmonella* sp. Lue-Hing et al. (1979) did not find any evidence of viral contamination of runoff, surface water, or groundwater at the Fulton County biosolids application site. Although the adsorption of viruses to clays precludes their movement to groundwater, Shaub et al. (1975) have shown that viruses adsorbed are still infectious.

Straub et al. (1992) measured the inactivation rate ($k = \log^{-10}$ reduction per day) of poliovirus type 1 and bacteriophages MS2 and PRD-1 in a laboratory study using two desert soils. Biosolids were added to a Brazito sand loam and Pima clay loam. They found that temperature and soil texture were the most important factors controlling inactivation when the soil was kept moist. As the temperature rose from 15 to 40ºC, the inactivation rate for poliovirus and bacteriophage MS2 increased; whereas, for the bacteriophage PRD-1, a significant increase in inactivation occurred only at 40ºC. Clay soils afforded more protection than sandy soils to all three viruses. Reduction in moisture content to less than 5% completely inactivated all three viruses within 7 days at 15ºC. Thus, a combination of moisture reduction and high temperature is effective in virus inactivation. These studies, under laboratory conditions using soil columns and constant parameters, can point to possible trends, but should not be taken as definitive behavior of organisms in the environment. Soils undergo fluctuations in moisture and temperature. These fluctuations, especially desiccation and high surface temperatures, will destroy pathogens.

Tables 8.3 and 8.4 provide data on the survival of some pathogens in soils.

Table 8.3 Survival of Bacteria in Soils

Organism	Soil	Temperature (ºC)	Survival time (days)
Salmonella sp.	Soil	–	15–7,280
Salmonella typhimurium	Soil	Summer sun	<28
	Soil	Summer shade	<70
Salmonella typhi	Soil	–	1–120
	Sandy soil	16–17	<29–<58
	Soil moist	–	<80
	Soil dry	–	<24
Tubercle Bacilli	Soil	–	>189
Leptospira	Soil	–	15–43
Coliform	Soil surface	–	38
Streptococcus spp.	Soil	–	35–63
Fecal streptococci	Soil	–	26–77

Sources: Rudolfs et al., 1950; Parsons et al., 1975; Golueke, 1983.

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Parasites

Sorber and Moore (1986) reported that parasites persisted the longest of most organisms in soils. Gerba (1983) found that air, desiccation, and sunlight result in rapid die-off. Protozoan cysts are highly sensitive to drying and are expected to survive in soil for only a few days in most soils. *Entamoeba histolytica* has been reported to survive 18 to 24 h in dry soil and 42 to 72 h in moist soil (Kowal, 1982). Helminth eggs and larvae can survive in soil for longer periods of time. Under favorable conditions of moisture, temperature, and sunlight, *Ascaris*, *Trichuris*, and *Toxocara* can remain viable and infective for several years (Little, 1980). *Ascaris* eggs can survive up to 7 years in soil (Sepp, 1980). However, Strauch et al. (1981) reported that *Ascaris* eggs are dependent on a host for survival, and thus die fairly quickly in both winter and summer when seeded biosolids are applied to forest land. In an East Bay Municipal Utility District (EBMUD) study, 12.9% of the soil samples contained viable helminth ova 3 years after biosolids' application (Theis et al., 1978). Feachem et al. (1980) reported that hookworms can survive for up to 6 months. Babayera (1966) indicated that *Taenia* could survive from several days to 7 months. Although the data on pathogen survival in soils are highly variable, the evidence suggests that most pathogens do not survive in soils for a great length of time. The soil environment is hostile. Temperature, moisture, and soil pH are the most important factors for pathogen survival. Pathogens die more quickly in warm weather than in colder weather as the soil surface heats up. Decreases in soil moisture hastens pathogen die-off. Soil moisture conditions vary with climate and soil physical properties.

Table 8.4 Survival of Some Viruses in Soil

Organism	Soil	Application System	Temperature (°C)	Survival Time	Reference
Poliovirus	Sand dunes (dry)				
Poliovirus type 1		Effluent		31 days	
			33	40+ days	Palfi, 1972
			30	Reduced by 4 log in 30 days	Moore et al., 1978
Poliovirus 1		Secondary effluent	Winter Summer	89 days 11 days	Tierney et al., 1977
		Activated sewage sludge	Winter Summer	96 days 7 days	Tierney et al., 1977
Coxsackie-virus	Sandy soil and clay	Dewatered, anaerobically digested	Winter	23 weeks	

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Table 8.5 Survival of Pathogens or Indicator Organisms on Plants

Organism	Plant	Survival Time	References
Poliovirus 1	Lettuce, radish	23 days	Tierney et al., 1977
Coliforms	vegetables, grass, clover	35 days6–34 days	Parsons et al., 1975
	Tomatoes	35 days	Engelbrecht, 1978
Salmonella typhi	Vegetables	7–53 days	Engelbrecht, 1978
Salmonella typhi	Vegetables and fruit	<1–68 days	Parsons et al., 1975
Shigella spp	Vegetables	2–10 days	Parsons et al., 1975
	Tomatoes	2–7 days	Engelbrecht, 1978
Vibrio cholerae	Vegetables	2 days	Engelbrecht, 1978
Tubercle bacilli	Radish	90 days	Engelbrecht, 1978
	Grass	10–49 days	Parsons et al., 1975
Entamoeba histolytica	Vegetables	3 days	Engelbrecht, 1978
	Vegetables	<1–3 days	Parsons et al., 1975
Tania saginata eggs	Pasture	90–365 days	Engelbrecht, 1978
Enteroviruses	Vegetables and fruit	4–6 days	Parsons et al., 1975

PATHOGENS ON PLANTS

Pathogens do not penetrate into fruits or vegetables unless their skin is broken (Rudolfs et al., 1950; Bryan, 1977). Bryan reviewed the early literature on the survival of pathogens on crops. Pathogen survival would be very short on fruits and vegetables exposed to sunlight and dry conditions. The survival on subsurface crops such as potatoes and beets would be similar to that in soil (Gerba, 1983). The edible portion of crops that does not come in contact with the soil or biosolids is less apt to be contaminated. This is the basis for the Part 503 regulations concerning Class B biosolids used for land application. Table 8.5 provides information on the survival of indicator organisms and pathogens on plants.

Kowal (1982) indicated that survival times of several bacterial pathogens ranged from less than 1 day to 6 weeks. Virus survival on the surface of aerial crops would be expected to be shorter than in soil, because of exposure to deleterious environmental effects, especially sunlight, high temperatures, drying, and washing off by rainfall (Kowal, 1982; Gerba, 1983). Gerba (1983) indicated that the intact surfaces of vegetables are probably impenetrable for viruses. Parasites have been reported to survive on plant surfaces for months.

Sepp (1980) reported that helminth eggs on grass survived over winter and remained infective in harvested hay. He earlier reported (1971) that *Ascaris* ova were destroyed in 27 to 35 days on vegetable surfaces during dry summer weather by desiccation.

In a study by Ohio University and the Ohio Farm Bureau Federation (USEPA, 1985), soil and forage samples were collected on three farms for parasitic ova and larvae. Samples were taken from both biosolids-treated and untreated pasturelands. The analysis was done before biosolids application and 7, 14, and 28 days following application. The study concluded that the risk of parasite transmission to animals

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from land-applied biosolids was indistinguishable from farms without such application.

Evidence from the literature proves that the survival rate of pathogens on plants is very short. Desiccation, temperature, and ultraviolet light are the most important factors in destroying pathogens on plants. Thus, the risk for humans consuming foods where biosolids are land applied is even lower since most of the biosolids are incorporated into the soil and do not come in contact with edible food crops. The risk to humans from pathogens in biosolids that are applied to non-edible crops, forestry, and fruit trees is essentially nil.

CONCLUSION

The soil environment is generally hostile to pathogens. Desiccation, soil temperature, and pH affect their survival. Decreases in soil moisture have resulted in a greater die-off rate of pathogens. Rises in soil temperature increase the die-off rate of pathogens. Soil acidity also lowers the rate of pathogen survival. Organic matter and clay affect retention, especially of viruses. Generally most pathogens are retained in the upper 5 to 15 cm of the soil.

The data show that bacteria and viruses do not survive in soils for extensive periods. Thus, the potential for bacteria and viruses to move through soils to groundwater is very low. Parasites are larger and heavier than bacteria and viruses and do not readily move through soils. Since most biosolids' applications are immediately incorporated into the soil, the potential for contamination of surface runoff is minimal. The low survivability of pathogens in soils also reduces the potential for surface water contamination.

Today most biosolids are incorporated into the soil before a crop is planted. Exceptions include pastures where liquid biosolids may be applied to an existing crop. Pathogens survive on plants for short periods of time as they are exposed to sunlight and ultraviolet light. Desiccation also plays a major role in reducing their survival.

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